

Exploring Early Parton Momentum Distribution with the Ridge from the Near-Side Jet

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Abstract. In a central nucleus-nucleus collision at high-energies, medium partons kicked by a near-side jet acquire a momentum along the jet direction and subsequently materialize as the observed ridge particles. They carry direct information on the early parton momentum distribution which can be extracted by using the ridge data for central AuAu collisions at $\sqrt{s_{NN}} = 200$ GeV. The extracted parton momentum distribution has a thermal-like transverse momentum distribution but a non-Gaussian, relatively flat rapidity distribution at mid-rapidity with sharp kinematic boundaries at large rapidities that depend on the transverse momentum.

In central high-energy heavy-ion collisions, the state of the parton medium during the early stage of a nucleus-nucleus collision is an important physical quantity. It furnishes information for the investigation of the mechanism of parton production in the early stages of the collision of two heavy nuclei. It also provides the initial data for the evolution of the system toward the state of quark-gluon plasma. Not much is known about the early state of the partons from direct experimental measurements.

Recently, the STAR Collaboration observed a $\Delta\phi$ - $\Delta\eta$ correlation of particles associated with a near-side jet in central AuAu collisions at $\sqrt{s_{NN}} = 200$ GeV at RHIC, where $\Delta\phi$ and $\Delta\eta$ are the azimuthal angle and pseudorapidity differences relative to a high- p_t trigger particle [1, 2, 3, 4]. The near-side correlations can be decomposed into a “jet” component with fragmentation and radiation products at $(\Delta\phi, \Delta\eta) \sim (0,0)$, and a “ridge” component at $\Delta\phi \sim 0$ with a ridge structure in $\Delta\eta$.

While many theoretical models have been proposed [5, 6, 7], a momentum kick model was presented to describe the ridge phenomenon [6, 7]. The model assumes that a near-side jet occurs near the surface and it kicks medium partons, loses energy along its way, and fragments into the trigger particle and other fragmentation products in the “jet” component. The kicked medium partons, each of which acquires a momentum kick \mathbf{q} from the near-side jet, materialize by parton-hadron duality as ridge particles. The ridge particle momentum distribution is related to the initial momentum distribution by a momentum shift. We can therefore extract the initial parton momentum distribution from the ridge data for central AuAu collisions at $\sqrt{s_{NN}} = 200$ GeV obtained by the STAR Collaboration [1, 2, 3].

We parametrize the normalized initial parton momentum distribution as

$$\frac{dF}{p_t dp_t dy d\phi} = A_{\text{ridge}} (1-x)^a \frac{e^{-\sqrt{m^2 + p_t^2}/T}}{\sqrt{m_d^2 + p_t^2}}, \quad (1)$$

where $x = \sqrt{m^2 + p_t^2} e^{|y| - y_b} / m_b \leq 1$, A_{ridge} is a normalization constant defined by $\int d\mathbf{p} dF/d\mathbf{p} = 1$, a is the rapidity fall-off parameter, y_b is beam parton rapidity, m_b is the beam parton mass, $m = m_\pi$, and m_d is a mass parameter introduced to give a better description of low- p_t ridge data. For lack of a definitive determination, we set y_b equal to the nucleon rapidity y_N and m_b equal to m , pending future definitive measurements of the ridge boundary. The observed ridge distribution is the final parton momentum distribution after jet-parton collisions, scaled by the average number of charged kicked partons per trigger, $\langle N \rangle$, that may be modified by a ridge attenuation factor f_R .

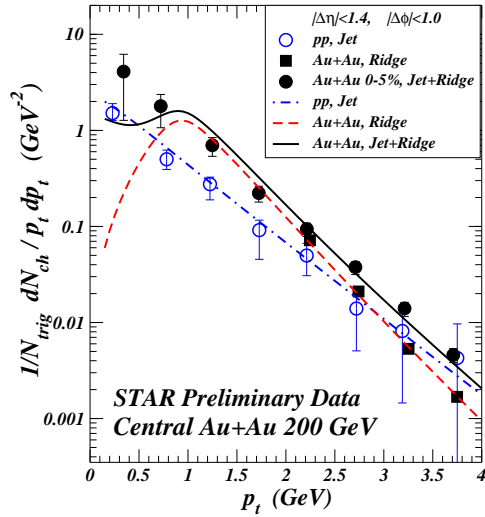


Fig. 1 Transverse momentum distribution of associated particles in pp and central AuAu collisions.

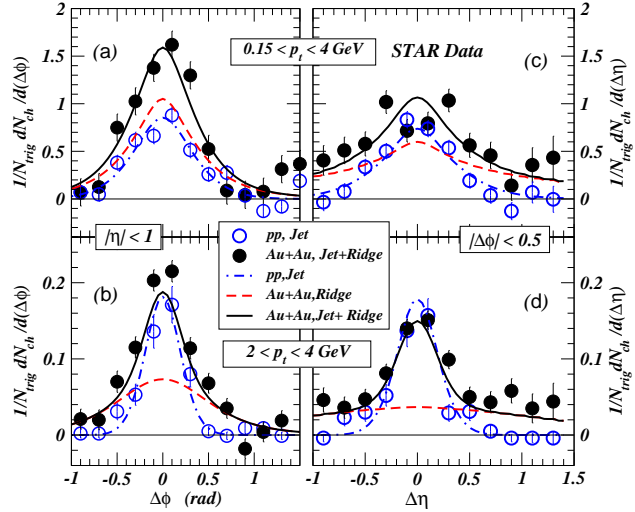


Fig. 2 Azimuthal angular and pseudorapidity distributions in pp and central AuAu collisions.

To infer the associated ridge particle yield from experimental data, we need to know the jet component in central AuAu collisions. The scaling relation between the fragments in the jet component and the trigger particle [2] allows us to treat the AuAu jet component per trigger as a pp near-side jet distribution, attenuated by a semi-empirical attenuation factor $f_J = 0.63$ [7]. The experimental pp near-side jet data, shown as open circles in Figs. 1 and 2, can be described by the dash-dot curves in these figures obtained from

$$\frac{dN_{\text{jet}}^{pp}}{p_t dp_t d\Delta\eta d\Delta\phi} = N_{\text{jet}} \frac{\exp\{(m - \sqrt{m^2 + p_t^2})/T_{\text{jet}}\} \exp\{-(\Delta\phi)^2 + (\Delta\eta)^2/2\sigma_\phi^2\}}{T_{\text{jet}}(m + T_{\text{jet}}) 2\pi\sigma_\phi^2}, \quad (2)$$

where $\sigma_\phi = \sigma_{\phi 0} m_a / \sqrt{m_a^2 + p_t^2}$, $\sigma_{\phi 0} = 0.5$, $m_a = 1.1$ GeV, $N_{\text{jet}} = 0.75$, and $T_{\text{jet}} = 0.55$ GeV.

Theoretical evaluation of both the jet component and the ridge component for central AuAu collisions leads to the total yield of associated particles. A self-consistent

comparison of the momentum kick model results with experimental data in Figs. 1, 2, and 3 then allows us to search for the initial parton momentum distribution. We find that the totality of the STAR associated particle data [1, 2, 3] from $p_t = 0.15$ GeV to 4 GeV and $|\eta|$ from 0 up to 3.9 in central AuAu collisions at $\sqrt{s_{NN}} = 200$ GeV, can be described by the average momentum kick per jet-parton collision $|\mathbf{q}| = 1$ GeV, the average effective numbers of kicked partons per jet $f_R\langle N \rangle = 4$, and the normalized initial parton momentum distribution Eq. (1) with

$$a = 0.5, T = 0.50 \text{ GeV}, \text{ and } m_d = 1 \text{ GeV}. \quad (3)$$

Fig. 1 shows good agreement between theoretical $dN_{\text{ch}}/N_{\text{trig}}p_t dp_t$ results with experimental charged hadron yields. Note that the theoretical ridge $dN_{\text{ch}}/N_{\text{trig}}p_t dp_t$ (the dashed curve) has a peak at $p_t \sim |\mathbf{q}| \sim 1$ GeV, as a result of the momentum kick. In Fig. 2, comparison of theoretical and experimental associated particle data indicates general agreement over azimuthal angles [Figs. 2(a) and 2(b)] and over pseudorapidities [Figs. 2(c) and 2(d)], for both $0.15 < p_t < 4$ GeV [Figs. 2(a) and 2(c)] and $2 < p_t < 4$ GeV [Figs. 2(b) and 2(d)]. The forward rapidity data in Fig. 3 have large uncertainties and the value of $a = 0.5$ gives reasonable agreement with experiment.

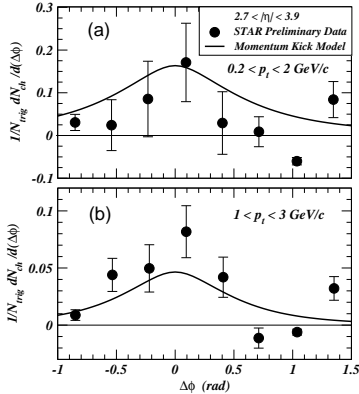


Fig. 3 Azimuthal distributions of associated particles in forward rapidities for central AuAu collisions.

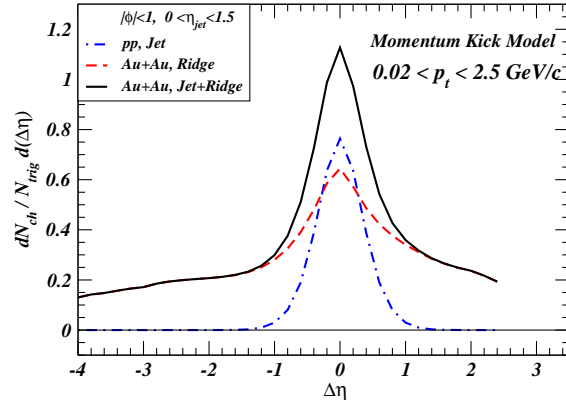


Fig. 4 Theoretical predictions of associated particle pseudorapidity distribution within the acceptance region of the PHOBOS detector.

Using the parameters we have extracted from the STAR ridge data for central AuAu collisions at $\sqrt{s} = 200$ GeV, we can predict the pseudorapidity distribution of associated particles for the PHOBOS experimental acceptance defined by $\Delta\phi \leq 1$, $0 < \eta_{\text{trig}} < 1.5$, $0.02 < p_t < 2.5$ GeV. The total associated particle yield is shown as the solid curve in Fig. 4. The pp jet yield and the associated ridge particle yield are shown as the dash-dot and the dashed curves respectively. The result has been corrected for $\Delta\eta$ acceptance. The present prediction up to large $|\Delta\eta|$ was found to agree well with experimental measurements obtained by the PHOBOS Collaboration [8].

The distribution (1) with parameters of Eq. (3) gives the normalized initial parton momentum distribution at the moment of jet-parton collision. We show this distribution in Figs. 5. It cannot be separated as the product of two independent distributions of

p_t and y . In Fig. 5(a), the momentum distribution for $y = 0$ and high p_t has a slope parameter T that is intermediate between that of the jet and the inclusive particles. This indicates that partons at the moment of jet-parton collision are at an intermediate stage of dynamical equilibration. The distribution as a function of p_t does not change much as y increases from 0 to 2. For $y = 3$, the maximum value of p_t is 1.54 GeV and the distribution changes significantly as the kinematic boundary is approached. For $y = 4$, the boundary of p_t is located at 0.55 GeV.

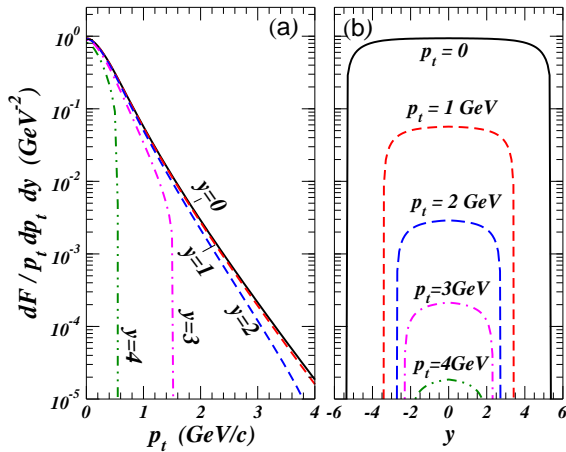


Fig. 5 Initial parton momentum distribution at the moment of jet-parton collisions.

associated with a near-side jet in central AuAu collisions at $\sqrt{s_{NN}} = 200$ GeV allows us to extract unique and valuable information on the medium parton momentum distribution at the moment of jet-parton collision. In the process, we also find the average momentum kick per jet-parton collision $|\mathbf{q}|$, and the average effective numbers of kicked medium partons per near-side jet $f_R\langle N \rangle$, in these collisions. They provide important empirical data for future investigations on the dynamics of parton production, parton evolution, and jet momentum loss.

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